Transformation of A Sustainable City Using Object-Oriented Techniques for Urban Green Space Planning – A Case Study of Lusaka City

* [1] Dr. **Penjani Hopkins Nyimbili,** [2] BEng. **Otilia Muyabi,** [3] MSc. **Masauso Sakala,** [4] Dr. **Alick R. Mwanza,** [5] Dr. **Ethel Tembo Mwanaumo,**
[6] Prof. Dr. **Erastus Misheng'u Mwanaumo** and [7] Prof. Dr. **Wellington Didibhuku Thwala**

[1, 2, 3 & 4] *Department of Geomatic Engineering, School of Engineering, University of Zambia, Lusaka, Zambia*
[5] *University of Zambia, Lusaka, Zambia*
[6] *Department of Civil and Environmental Engineering, School of Engineering, University of Zambia, Lusaka, Zambia*
[6] *University of South Africa (UNISA), Department of Civil Engineering, College of Science, Engineering and Technology, Pretoria, 0003, South Africa.*
[7] *Faculty of Engineering, Built Environment and Information Technology, Walter Sisulu University, Eastern Cape, South Africa*
E-mail [1]: penjani.nyimbili@unza.zm, E-mail [2]: omuyabi@gmail.com, E-mail [3]: masauso.sakala@unza.zm, E-mail [4]: armwanza@unza.zm,
E-mail [5]: ethel.mwanaumo@yahoo.com, E-mail [6] : erastus.mwanaumo@unza.zm, E-mail [7]: wdthwala@wsu.ac.za

Abstract
Effective land resource management and sustainable development, particularly in urban green spaces, rely on strategic land planning and mapping techniques such as Remote Sensing. This study utilises object-based classification techniques, employing Google Earth Engine and Quantum Geographic Information Systems (QGIS), to examine Lusaka City's green space encroachment. Findings reveal a 59% increase in built-up areas towards the north-east direction and a 2% decline in green spaces towards the south-east part of Lusaka. The implications are significant, highlighting the urgent need for intervention to preserve the city's environmental balance. Immediate action is essential, requiring rigorous regulations, community engagement, and stakeholder collaboration. Furthermore, the study underscores the critical role of remote sensing in monitoring urban green spaces and identifying sustainability threats, emphasising the importance of prioritising the protection and improvement of green spaces through comprehensive land use planning and land use land cover mapping through the use of object-based classification techniques.
Keywords: Land resource planning; Urban green spaces; Remote Sensing; Object-based classification; Google Earth Engine.

1. Introduction

Urban ecosystems worldwide are undergoing rapid transformation due to the ongoing process of urbanisation, which profoundly influences both the environment and human societies. The presence of vegetation within urban landscapes plays a pivotal role in mitigating the adverse effects of this transformation, offering a multitude of benefits ranging from improved well-being to crucial environmental services such as carbon sequestration and noise reduction (Gülçin & Akpınar, 2018; Afara et al., 2024; Amen et al., 2024). However, despite these advantages, the monitoring and preservation of urban vegetation remain challenging tasks, prompting the exploration of automated mapping techniques driven by advancements in remote sensing technology (Kerselaers et al., 2013).

One essential tool for guiding urban resource management and monitoring environmental changes is Land Use Land Cover (LULC) mapping. This tool is particularly crucial in rapidly urbanising regions like Zambia, where dynamic patterns of urban growth, especially in vulnerable informal settlements, pose unique challenges (Simwanda, 2018). The absence of consistent, detailed base maps impedes global efforts to improve these settlements by offering better services for citizens, highlighting the necessity for rapid and dependable techniques to collect information on their layouts (Simwanda & Murayama, 2018).

The intricate interaction of demographic and land-use changes inherent in urbanisation underscores the importance of effective urban planning. Global urbanisation is making comprehensive urban planning more and more important since it affects open spaces, biodiversity, transportation, public health, and daily urban life (Kim, 2022). To facilitate such planning, an in-depth understanding of city growth, territorial usage, and the dynamics of urbanisation is essential (Hansberg, 2007; Loureiro, 2014; Nyimbili et al. 2023)

In the context of urban landscapes, areas with populations exceeding 5,000 serve as centres for diverse activities (Dijkstra et al., 2020). Within this fabric, green spaces such as Forest 27, Kalimba Farm, Monkey Pools Farm, and Chaminuka Game Reserve, found in Lusaka city, play a crucial role, contributing significantly to the well-being of inhabitants and offering essential ecosystem services. Access to Urban Green Spaces (UGS), aligned with Sustainable Development Goal (SDG) No. 11, acts as a natural countermeasure to climate change, mitigating heat island effects, reducing air pollution, and regulating water (Gülçin & Akpınar, 2018).

Moreover, urban planning aided by object-based classification methods using remote sensing, not only facilitates the creation of crucial maps but also enables efficient resource management. This approach provides initial data for research in various domains, including epidemics, climate change, flood mitigation, and geological exploration (Gülçin & Akpınar, 2018). In regions experiencing rapid urbanisation such as Zambia, urban planning becomes an indispensable tool in

mitigating challenges posed by unplanned settlements, especially considering the significant population surge witnessed in recent years.

Despite the numerous advantages provided by urban green spaces, including their role in enhancing sustainability and liveability, little is known about their current state and the challenges they face in dynamic urban centres such as Lusaka, Zambia's capital. This study aims to address this gap by objectively analysing the extent of urban green areas in Lusaka, identifying factors contributing to their decline, and proposing management and preservation solutions. By doing so, this research endeavours to contribute to the sustainable development and resilience of urban ecosystems in Zambia and beyond.

To achieve these goals, this study leverages advanced techniques in remote sensing and Geographic Object-Based Image Analysis (GEOBIA), building upon a rich body of knowledge and methodologies established in previous research. This paper provides a comprehensive review of relevant studies and methodologies, offering insights into the evolution of remote sensing techniques, classification approaches, and case studies focused on mapping urban green spaces. In order to provide a comprehensive understanding of the urban landscape under study, Figure 1 presents the population distribution of Lusaka, as a way of understanding the demographic dynamics shaping the city.
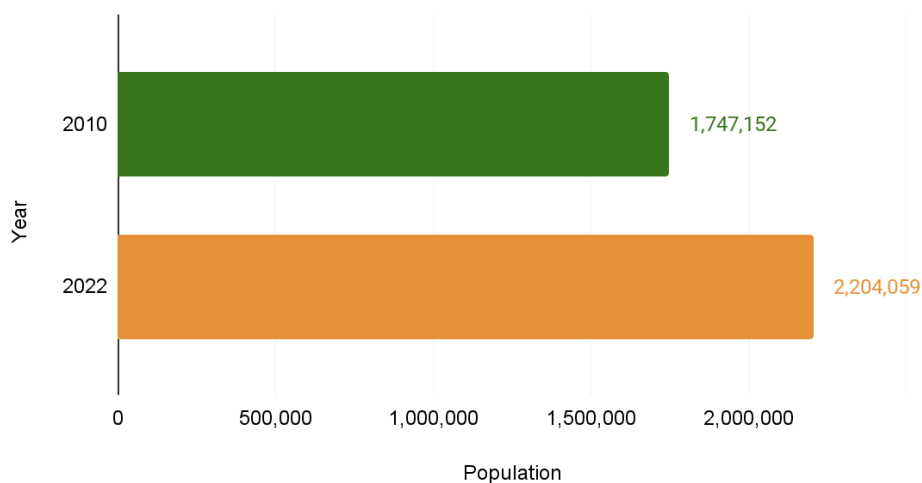

Figure 1. The population of Lusaka - Source: Zambia Statistics Agency Preliminary report (ZSA, 2022)

Additionally, Figure 2 depicts Lusaka's settlement map delineating the spatial distribution of various settlements within the city. These figures served as valuable references for analysing the patterns of urbanisation and identifying areas of interest that were further investigated.
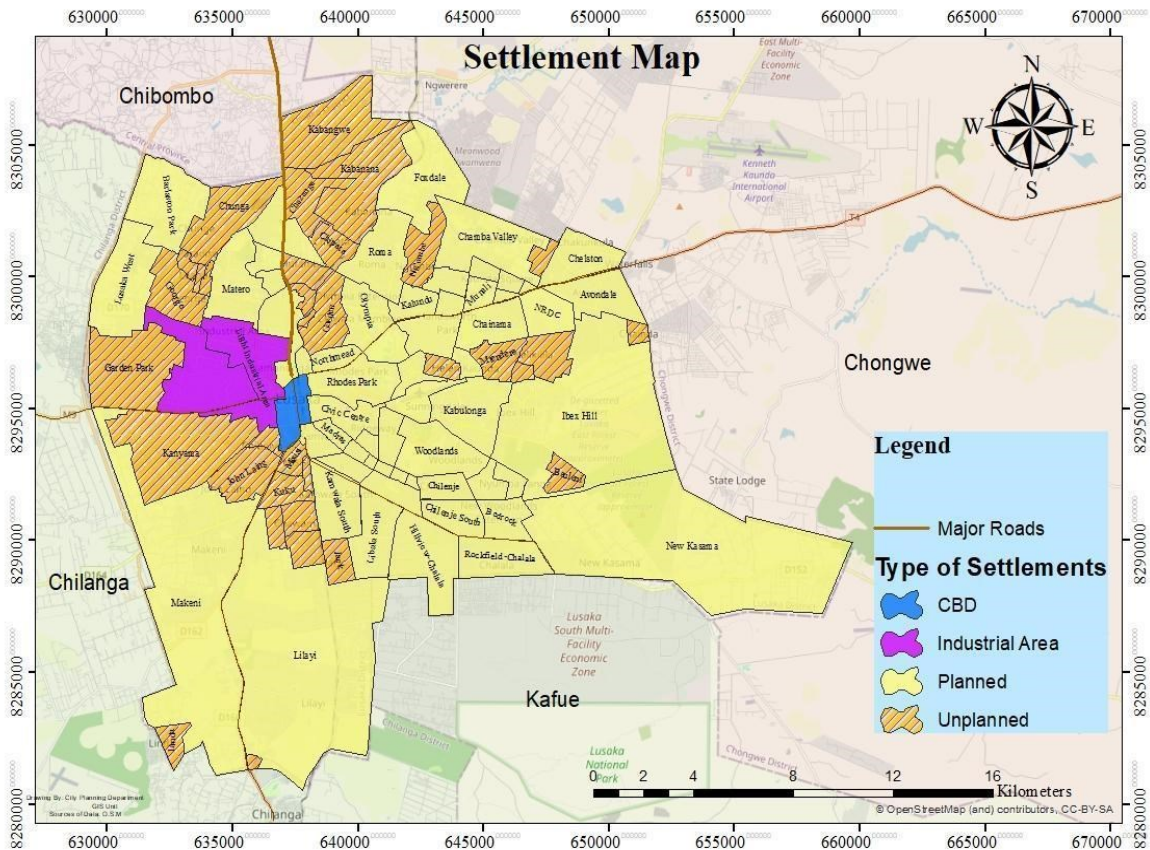
Figure 2. Lusaka's settlement map

Numerous studies have focused on predicting urban expansion, relying on remote sensing (RS) satellite imagery as a critical tool for analysing alterations in the physical environment, encompassing ecosystems and land use on the Earth's surface (Kim et al., 2022). However, the utilisation of RS data often necessitates mapping through image processing technology before utilisation, potentially leading to errors or distortions in land use classification. To address this limitation, the present study employs precise classification data derived from land cover map imagery. The integration of remotely sensed data with geographical information has been a longstanding endeavour, dating back to the launch of the first Landsat satellites, with physical geographers at the forefront of this endeavour (Franklin, 2001). Early on, researchers recognized the challenge of mapping vegetation communities with high floristic detail using available satellite multispectral imagery and began incorporating digital maps of environmental variables into the mapping process (Sedogo, 2002). These methods, including Geographic Object-Based Image Analysis (GEOBIA), have demonstrated enhanced results with higher-resolution images, albeit demanding significant computational and storage resources (Blaschke, 2010; Tassi et al., 2021). Google Earth Engine (GEE), equipped with advanced segmentation algorithms, addresses long-standing challenges in complex segmentation and classification steps encountered in traditional image processing software (Vizzari, 2020). This approach has proven effective for Land Use/Land Cover (LULC) mapping across various datasets and regions, showcasing improvements in mapping accuracy when integrated with texture features derived from Grey Level Co-occurrence Matrix (GLCM) analysis (Vizzari, 2020). Several case studies offer valuable insights into mapping urban green spaces, providing instructive examples to contextualise the concepts and methods used (Koskivaara & Lähtinen, 2023; Gülçin & Akpınar, 2018).

1.1. Research Question
This study's research questions are:
- What is the area coverage of urban green spaces in the city of Lusaka?
- What is the rate of change in urban green spaces in the city of Lusaka?
- What are some of the factors that are responsible for the decline of green spaces?

1.2. Objectives
This study's research questions are:
1.2.1 Primary Objective:
- To evaluate the amount of urban green space within the city of Lusaka.

1.2.2 Secondary Objectives
- To use object-based classification techniques and geographic information systems (GIS) to accurately measure and evaluate the degree of land encroachment in Lusaka.
- To determine the remaining area of urban green space within the city of Lusaka.
- To ascertain the area of the built-up environment within the city of Lusaka.

1.3. Study Area
The City of Lusaka, which has a population of 2,204,059 serves as the capital of Zambia (Agency, 2022). The City of Lusaka is part of the province of Lusaka which has six districts, namely Chilanga, Chongwe, Kafue, Rufunsa, Luangwa, and Lusaka, with Lusaka having the highest population.
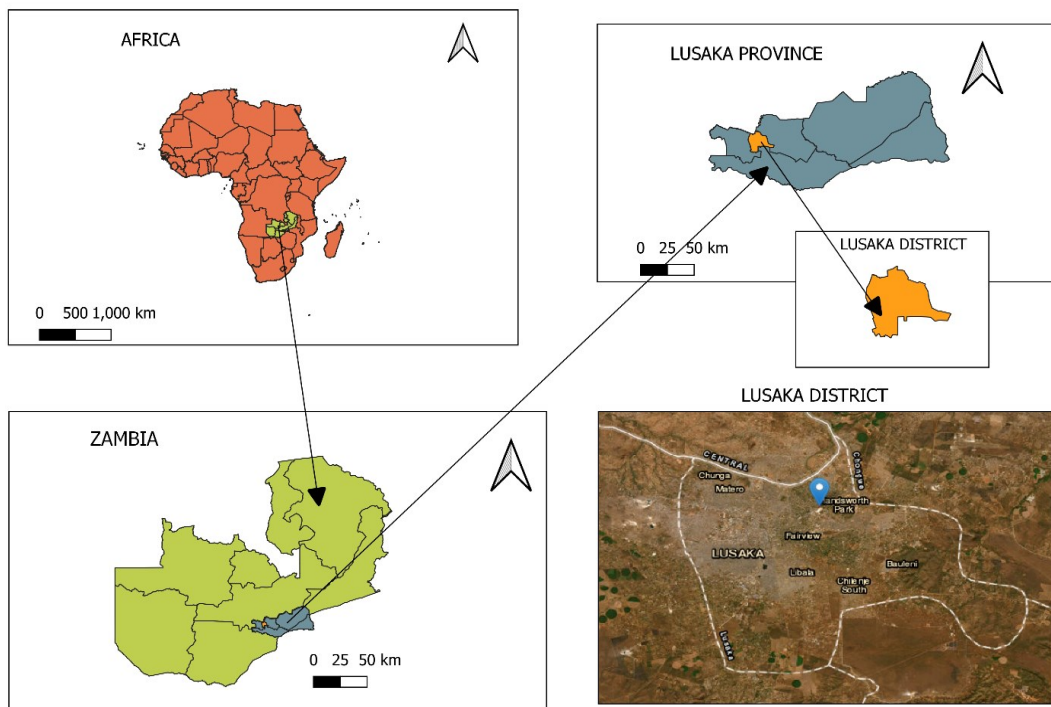

Figure 3. Study Area

1.4. Structure of the Paper
- An overview of relevant studies on urban green spaces is given in Section 2.
- The methodology used in this study, including methods for gathering and analysing data, is described in Section 3.
- The study's results, including the amount of urban green space, are presented in Section 4.
- Section 5 delves into the significance of findings regarding Lusaka's urban green spaces. It serves as a crucial discussion point, translating research insights into actionable measures.
- In Section 6, the conclusion effectively integrates the significance of the findings with actionable recommendations for the management and preservation of urban green spaces in Lusaka. The conclusion serves as a pivotal point for informed decision-making and sustainable urban development efforts.

2. Urban Green Space and Remote Sensing
A significant amount of research has been done on the prediction of urban growth through the use of remote sensing (RS) satellite data. Of particular interest has been the analysis of changes in the physical environment, such as ecosystems and land use on the surface of the Earth (Yin, 2021; Luan et al., 2021). When determining how human activity has affected ecosystems, natural resources, living areas, and the physical environment, remote sensing data is essential. However, it is important to recognize that data processing technology has its limitations, which can lead to errors or distortions in land use classification. In order to address this problem, the current work uses accurate categorization data obtained from land cover map images.

2.1. Integration of Remotely Sensed Data and Geographic Information
Since the first Landsat satellites were launched, physical geographers have been at the forefront of the integration of remotely sensed data with geographical information. The difficulty of tracking botanical communities using available

satellite multispectral information with great floristic resolution was one of the things identified by Franklin (2001). Referring to these as collateral or ancillary data, they added computerised maps of environmental variables, such as topography and geology, into the mapping process (Sedogo, 2002). These days, it is common to view remotely sensed data as ancillary to other data in a geographic information system (Michalak, 1993). Popular open-source GIS, QGIS, has proved helpful in combining and evaluating these kinds of datasets for a range of uses in environmental studies and urban planning.

2.2. Land Use Land Cover (LULC) Classification Approaches
To distinguish between various land cover types, whether pixel- or object-based, Land Use Land Cover (LULC) classification techniques generally compute the spectral signatures of classes of interest using training data (Tassi et al., 2021). With an emphasis on identifying and categorising objects produced at different scales, Geographic Object-Based Image Analysis (GEOBIA) has grown in prominence (Blaschke, 2010; Tassi et al., 2021). An essential first step is object identification, which is achieved by grouping comparable pixels into picture clusters using segmentation and clustering and subsequently turning those clusters into vectors (Ren & Malik, 2003; Vizzari, 2020). Higher-resolution images have shown improved results with these technologies; however, they do require a large amount of processing and storage power. With a large selection of tools and plugins for processing and analysing remote sensing data, QGIS offers a complete platform for applying and improving LULC classification methods.

2.3. Effective Planning for Sustainable Residential Development
Several case studies provide insightful information about practical planning techniques for sustainable residential development. The study by Koskivaara and Lähtinen (2023) explores how important land-use planning is to Finland's sustainable residential development. Using a regional innovation system approach, their study looks at stakeholder involvement, planning processes, and sustainability goals in various parts of the nation. The results demonstrate a strong correlation between informal planning systems and the sustainability objectives of municipalities. Research and governance organisations have made noteworthy contributions to the findings.

2.4 Object-Based Classification for Sustainable Development
In research on remote sensing, object-based image analysis, or OBIA, has become an effective instrument. In order to create LULC maps, Tassi and Vizzari (2020) proposed an object-based method in Google Earth Engine (GEE) that makes use of machine learning algorithms. Their approach showed promising results when applied to medium-high and high-resolution images (Sentinel 2 and Planetscope), but its accuracy with Landsat 8 (L8) data that only uses the 30-metre bands was less than satisfactory. Google Earth Engine (GEE) covers analysis, classification, and output visualisation while also providing access to highly parallelized algorithms, addressing long-standing issues with complex segmentation and classification procedures seen in traditional image processing tools. These results can be enhanced by offering more tools for spatial analysis and making data interpretation and visualisation easier. Three segmentation methods are available for use within GEE: K-means, G-means, and Simple Non-Iterative Clustering (SNIC). Known for its reduced memory usage and computational efficiency when compared to K-means and G-means, SNIC has proven effective in object-based mapping applications. When combined with texture features from Grey Level Co-occurrence Matrix (GLCM) analysis, this method has demonstrated positive attribute mapping accuracy for LULC mapping across a variety of datasets and geographical areas. Using the OBIA technique to distinguish between formal and informal areas requires the ability to calculate image textural indices based on second-order statistics, which is made possible by the GLCM algorithm. By offering more geographical analysis tools and enabling data visualisation and interpretation, QGIS can support these analyses (Ren & Malik, 2003).

3. Materials and Methods
The study used a systematic approach to investigate encroachment on urban green spaces in Lusaka from 2016 to 2023, relying heavily on remote sensing techniques. Quantitative analysis was essential, helping determine encroachment rates during this time. Importantly, the use of Sentinel satellite imagery allowed for a detailed assessment of land use changes, offering valuable insights into urban expansion. Through this research, the utilisation of remote sensing methods, alongside tools like Quantum GIS and Google Earth Engine (GEE), allowed us to conduct thorough analyses, ensuring a better interpretation of land cover changes in Lusaka.

At the same time, the study upheld rigorous ethical considerations throughout its research endeavour. We took active steps to address broader ethical concerns, including safeguarding privacy, promoting environmental justice, and ensuring data accuracy. By prioritising the reduction of security risks and advocating for fair data usage, the study aimed to maintain the credibility of its findings. Additionally, initiatives to involve stakeholders emphasised our commitment to transparency and accountability, creating an inclusive research environment. Through the careful application of remote sensing

techniques and a steadfast commitment to ethical principles, the study established a robust framework for investigating urban green space encroachment in Lusaka.
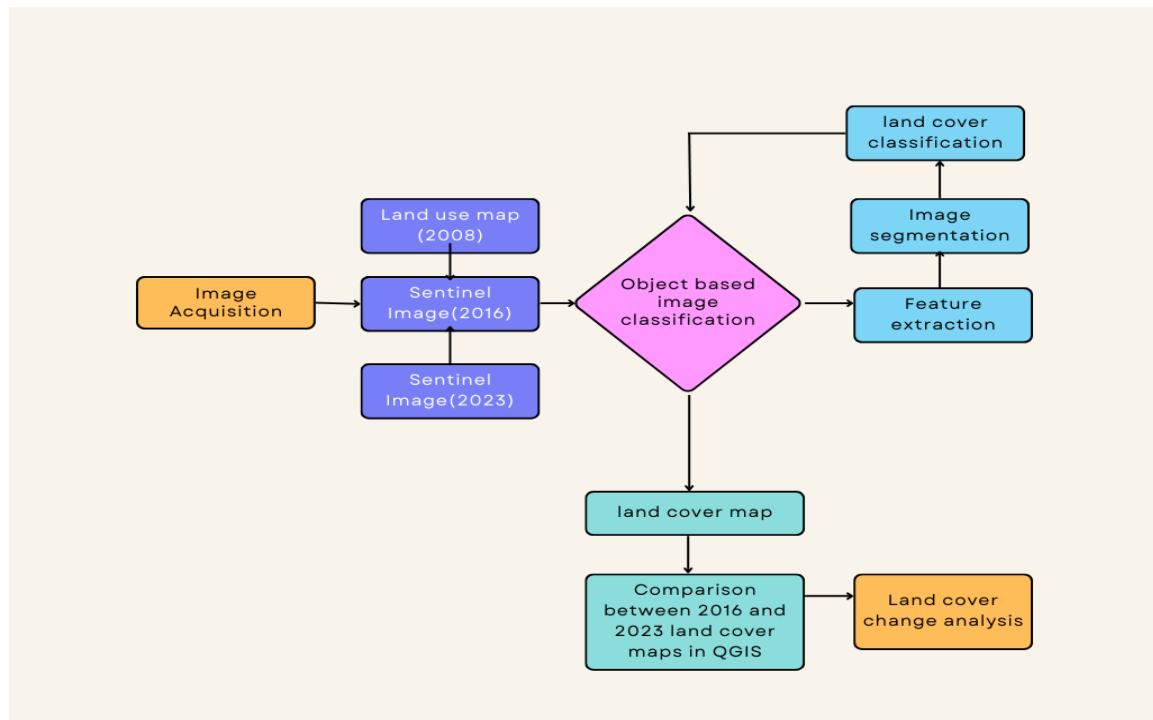

Figure 4. Methodology

Remote sensing techniques were fundamental for data collection in this study, which involved acquiring imagery through the Google Earth Engine (GEE) platform to visualise Lusaka City, our area of interest, and quantify urban green spaces. Visual interpretation of this imagery facilitated the collection of training data to educate GEE algorithms in distinguishing between various land cover classes. Geographic Information Systems (GIS), specifically QGIS, played a crucial role in measuring the extent of each land cover class and providing further analysis and comparison of land cover changes through the Semi-Automatic-Classification (SCP) toolbox. By examining different land cover classes, changes in land cover in Lusaka City were analysed. The integration of remote sensing and GIS aimed to gather comprehensive data and insights for effective urban green space management. To comprehensively assess green spaces within Lusaka City, this study employed geospatial and statistical analysis methodologies using QGIS software. Leveraging remote sensing data, distinctions were made between built-up regions, urban green spaces, and areas impacted by land encroachment. Geospatial tools within QGIS were then utilised to accurately quantify the extent of urban green spaces. Statistical analyses were then conducted to identify and understand contributing factors to the observed decline in these green areas.

3.1. Data Collection
3.1.1 Data collection
Sentinel satellite images from 2016 to 2023 were chosen as they provide high-resolution data suitable for studying land cover. Pre-processing methods, including cloud masking and atmospheric correction, were applied to enhance the quality of the imagery. Additionally, reference data such as the 2008 land use map of Lusaka City (shown in Figure 5) were utilised for validation purposes. The Google Earth Engine (GEE) code editor tool was then used to collect the data for this study. Through this platform, the image was obtained from the cloud storage of the GEE Platform, with the selection of the image of interest achieved by applying filters based on date and region of interest.
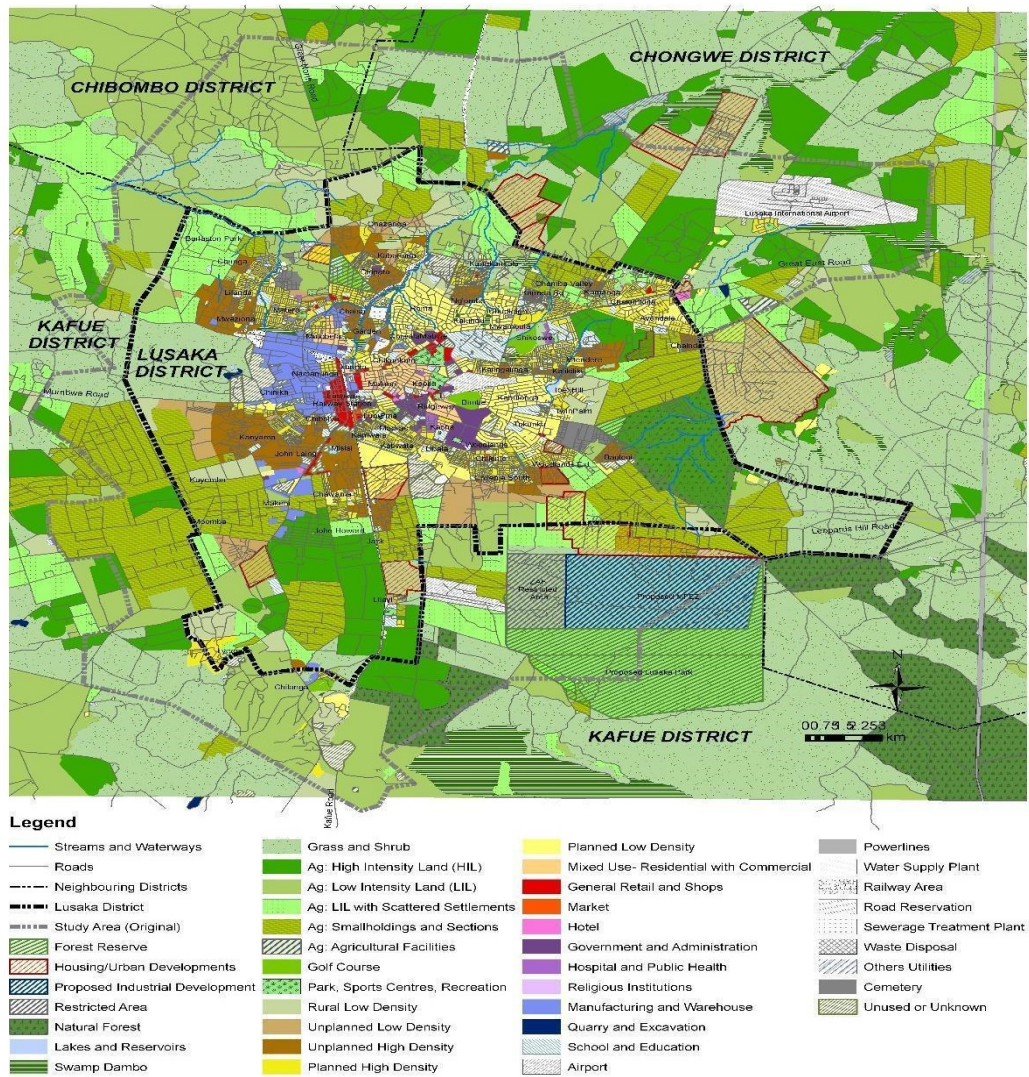
Figure 5. Existing land use map (2008) (Source: Lusaka City Council)

3.1.2 Sentinel 2 Imagery

Sentinel 2 data from the years 2016 and 2023 was utilised for the image classification. Sentinel 2 imagery has a temporal resolution of 10 days and a spatial resolution of 10m in bands B2, B3, B4 and B8; 20m in bands B5, B6, B7, B8a, B11, B12, and 60m in bands B1 and B9, respectively. Bandwidths range from 0.443 to 2.19 micrometres. This allows for the accurate identification of land covers. More details regarding the sentinel 2 imagery are provided in Table 1.

Table 1. Sentinel 2 Imagery Band Parameters

Band	Description	Wavelength(μm)	Spatial resolution(m)
1	Coastal aerosol	0.443	60
2	Blue	0.49	10
3	Green	0.56	10
4	Red	0.665	10
5	Red edge 1	0.705	20
6	Red edge 2	0.74	20
7	Red edge 3	0.783	20
8	Near Infrared (NIR)	0.842	10
8a	Red edge 4	0.865	20
9	Water vapour	0.945	60
11	Short Wave Infrared (SWIR 1)	1.61	20
12	Short Wave Infrared (SWIR 2)	2.19	20

3.2. Data Analysis

The data analysis process encompassed the collection, categorization, and assessment of images. We employed supervised classification to categorise land cover classes, utilising training data from the study area. Object-based classification methods, which integrate contextual and geographic information, were favoured for their enhanced accuracy. Contextual details were incorporated into the analysis through the selection of training data representing relevant features, while geographic information was spatially delineated using boundary-clipped maps. This methodology ensured that classification techniques accounted for both the surrounding context and specific geographic characteristics, thus enhancing accuracy. To evaluate how reliable the classification findings are, evaluation criteria such as total accuracy were used.

3.2.1 Land Cover Classification

The Google Earth Engine code editor was used to classify the Sentinel 2 imagery for the years 2016 and 2023 using the object-based classification technique. The ability of the object-based classification method to segment images and group features based on the spectral and spatial properties of the features by using the image bands led to its selection.

3.2.1.1 Image Acquisition and Image Filtering

Through the Google Earth Engine code editor, Sentinel images were acquired from the catalogue. By specifying Sentinel-2 from other Sentinel images, we obtained the required data for this research. Filters were subsequently applied to ensure coverage of our region of interest, Lusaka City, during the specified years. This was accomplished by setting bounds on both the date and region of interest.

3.2.1.2 Feature Extraction and Image Segmentation

Following the selection of a seed size for segmentation set at 5, features were extracted and image bands were input for the image classification process. This allowed algorithms to partition the image into sections, facilitating accurate feature classification.

3.2.1.3 Image Classification

Once the bands intended for classification were chosen and the training dataset input, involving the selection of points representing various land cover classes through supervised classification, this data was utilised for further classification using the random forest (RF) classifier. Upon completion of the classification process, different features were classified into distinct land cover types, including Bare Land, Built-Up Areas, Urban Green Spaces, Roads, and Water.

3.2.2 Land Cover Change Analysis

The analysis of land cover change was conducted both in Google Earth Engine, utilising pixel counts, and in QGIS, through the utilisation of the SCP toolbox. Using the tools available in the toolbox, the areas within each land cover class were calculated. By comparing these results between the 2016 and 2023 land cover maps, differences were identified. Subsequently, the obtained results were analysed to draw meaningful conclusions.

3.3. Limitations

Potential errors caused by elements such as cloud cover and atmospheric conditions in satellite photography are some of the acknowledged limitations. When interpreting changes over time, there may be uncertainties introduced by depending solely on historical land use data and maps. The precision of the study may also be impacted by underlying limitations of remote sensing techniques, such as restrictions on spatial and spectral resolution.

4. Results

This study aimed to assess the rate of green space encroachment in the city of Lusaka. This was achieved through the creation of land cover maps, as outlined below in Figures 6, 7 and 8 and Table 2.
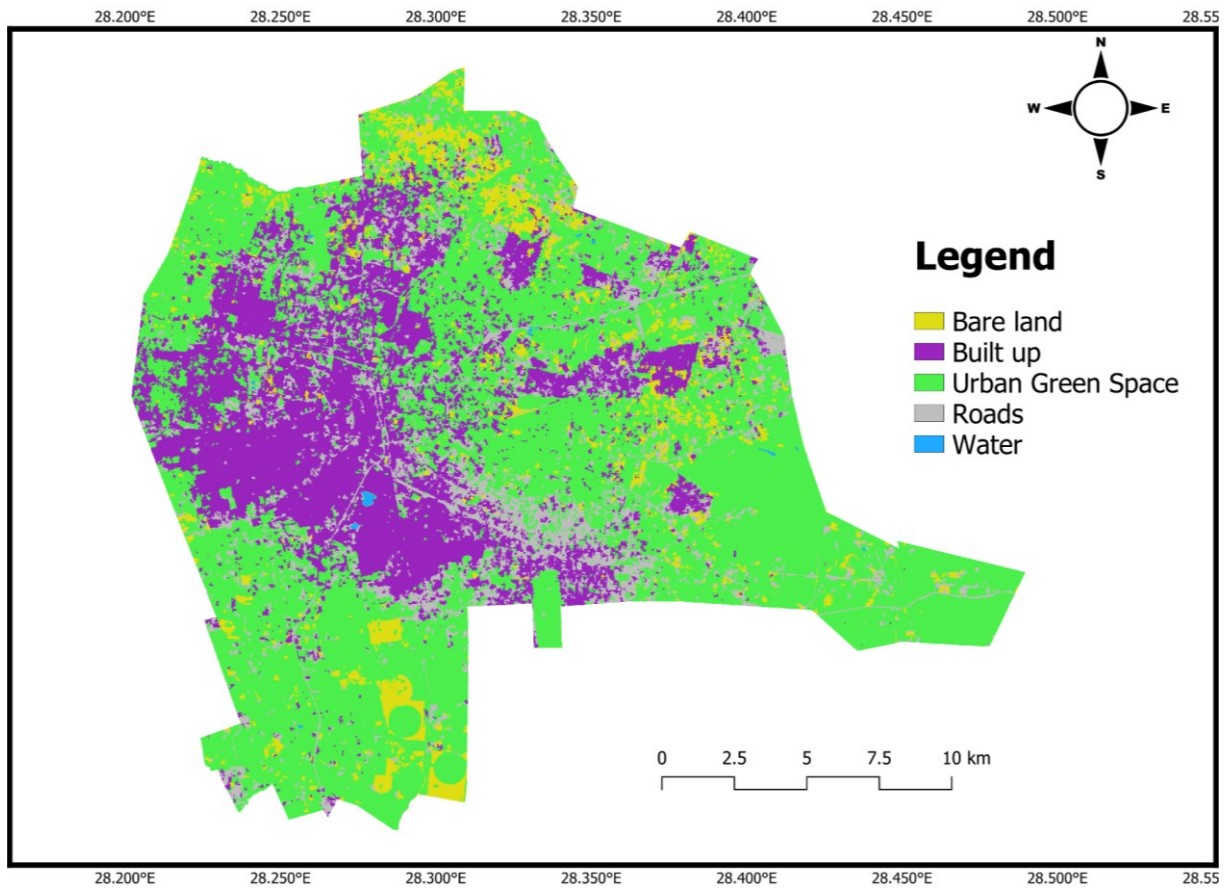
Figure 6. Land Cover Map (2016)

The distribution of land cover types in the Lusaka district in 2016 is shown in Figure 6. The environment was mostly made up of urban green space, with built-up regions, bare ground, roads, and water bodies following.
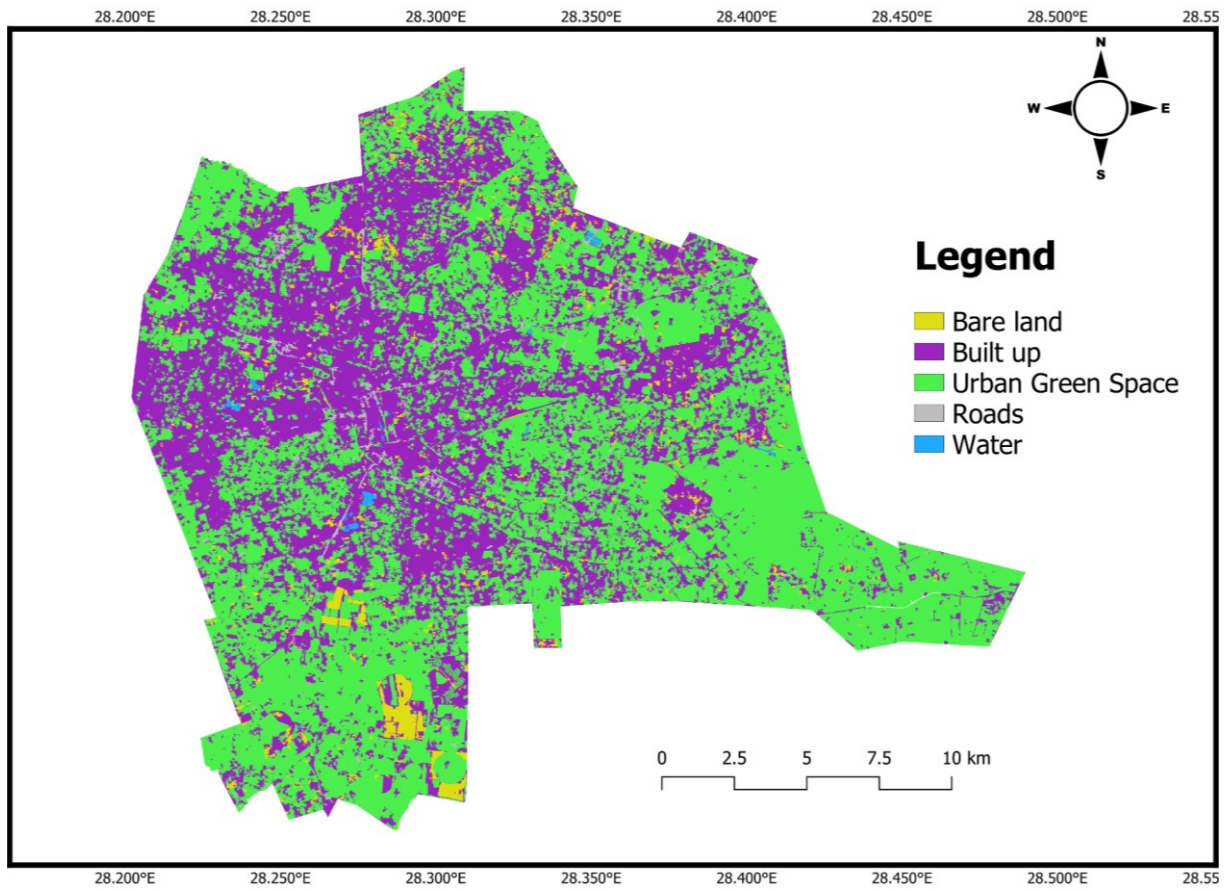
Figure 7. Land cover map (2023)

The distribution of land cover in the Lusaka district in 2023 is depicted in Figure 7. Over the seven-year period, there have been notable changes seen in Built-up areas, Bare land, Roads, and Water bodies. However, Urban Green Spaces continue to be the predominant land cover category.
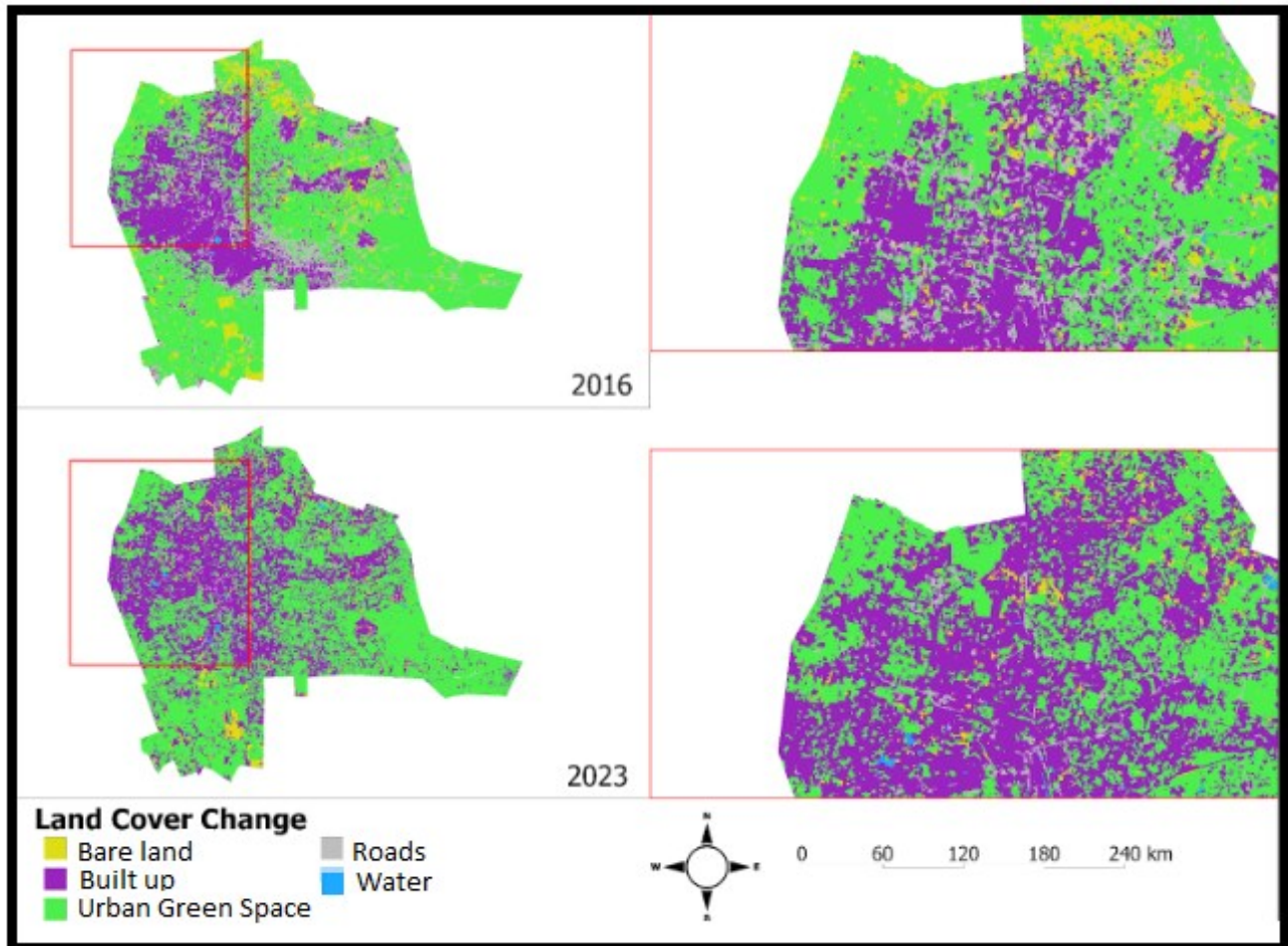

Figure 8. Land cover maps for the years 2016 and 2023

A visual representation of the types of land cover that have changed between 2016 and 2023 is provided in Figure 8, which highlights notable changes during the seven years.

Table 2. Land Cover classification outputs: area in hectares (ha)

Land Cover	Area In 2016 (ha)	Area In 2023 (ha)	Land Cover Change (ha)	Land Cover Change (%)
Bare Land	2,307.07	992.39	-1,314.68	-56.98
Built-Up	8,855.43	14,140.08	5,284.66	59.68
Urban Green Space	19,813.25	19,420.39	-392.86	-1.98
Roads	4,156.58	521.65	-3,634.93	-87.45
Water	34.11	86.20	52.09	152.72

To ascertain the overall accuracy of the land cover change assessment, the total accuracy was calculated based on the land cover change percentages. This calculation involved summing the absolute values of the change percentages and subtracting the result from 100%.

Total Accuracy = 100% - (|(-56.98)| + |59.68| + |(-1.98)| + |(-87.45)| + |152.72|)

Total Accuracy ≈ 100% - (56.98 + 59.68 + 1.98 + 87.45 + 152.72) ≈ 74.19%

Therefore, the value of 74.19% provides a comprehensive assessment of the overall accuracy of the land cover change analysis. Furthermore, this assessment was confirmed by utilising the semi-automatic plugin in QGIS, resulting in an overall accuracy value of 74.16%.

Between 2016 and 2023, the distribution of land cover types in the Lusaka district remained relatively stable, with Urban Green Space maintaining its dominant position. However, significant changes were observed in built-up areas and roads,

indicating urban expansion and infrastructure development. Table 2 provides detailed information on land cover types in Lusaka for both years.

Notably, the graphical representation of Table 2 (Figure 9) vividly illustrates these changes. It shows the percentage shift in various land cover types over the seven-year period, with built-up areas experiencing the most substantial increase. This graphical representation offers a clear visualisation of the extent of land cover changes in Lusaka City.
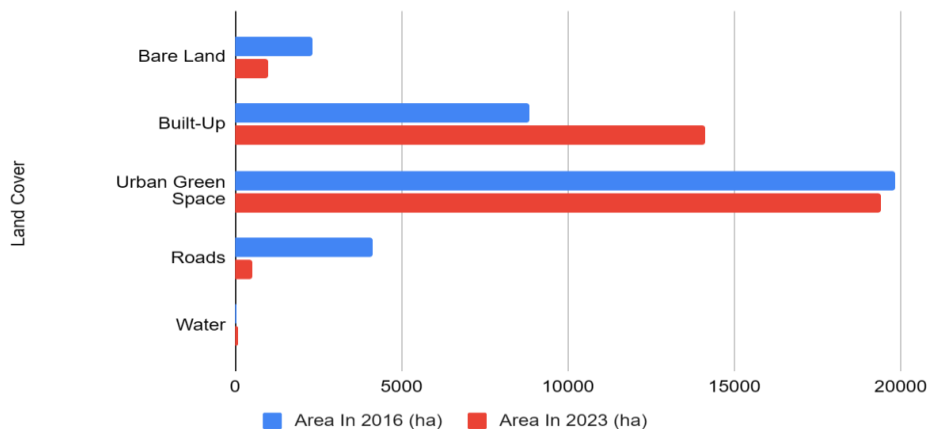

Figure 9. Land Cover Change in Lusaka City (2016 to 2023)

5. Discussions

5.1 Interpretation of Results

Remote sensing (RS) satellite imagery has provided valuable insights into the dynamics of Urban Green Spaces (UGS) in Lusaka. By accurately classifying this imagery, our research has revealed significant changes in land cover over the past seven years. These changes include a decrease in bare land, a notable 57% expansion in built-up areas, and a slight 2% reduction in urban green spaces. These shifts reflect the growing population and the demand for residential areas. Such transformations underscore the complex interplay between urbanisation, environmental conservation, and sustainable development in rapidly expanding cities such as Lusaka.

5.2 Comparison with Literature

Our findings are consistent with the research done by the Ministry of Local Government and Housing (MLGH), Lusaka City Council (LCC), and the Japan International Cooperation Agency (JICA), (JICA, 2009), and the research done by Yin et al. (2021) and Luan et al. (2021), emphasising the critical function of RS data in assessing changes in the Earth's surface physical environment and land use. It is imperative to recognize, meanwhile, that mapping using image processing technology has limits that could result in inaccurate or distorted land use classification. To address these difficulties, our research makes use of accurate categorization data obtained from land cover map images, which improves the precision and dependability of our conclusions. Moreover, the combination of geographical information with remotely sensed data, as emphasised in the research done by Tassi et al. (2021) and Tassi and Vizzari (2020), underscores the significance of utilising advanced methodologies such as Geographic Object-Based Image Analysis (GEOBIA). GEOBIA makes it easier to identify vegetation groups with great floristic detail and allows for a deeper comprehension of changes in land cover by classifying and defining objects created at different scales.

5.3 Limitations

While our research has advanced the use of RS technology and image processing methods, it acknowledges limitations, especially in dynamic urban environments like Lusaka. Relying solely on historical data and satellite imagery in such areas can lead to classification errors in land cover assessment. Future investigations must employ robust validation techniques and integrate additional datasets, such as drone imagery, to address these challenges. Drone technology offers high-resolution data, providing detailed insights into land cover characteristics and complementing satellite-derived information. By combining satellite and drone imagery, researchers can enhance the accuracy of land cover maps, facilitating informed decision-making for urban planning and environmental management initiatives in cities like Lusaka.

6. Conclusions

The assessment of urban green spaces in Lusaka, conducted between 2016 and 2023 using remote sensing techniques and Geographic Information Systems (GIS), has yielded crucial insights into the city's evolving landscape. The primary objective was to evaluate the extent of urban green space within Lusaka, employing remote sensing technologies and GIS analysis.

The study also aimed to measure land encroachment and determine the remaining area of urban green space amidst urbanisation.

Analysis of Sentinel 2 satellite images and remote sensing data revealed significant changes in land cover percentages within Lusaka over the study period. Notably, there was an alarming 59.68% increase in built-up areas, indicating extensive urbanisation and land development. Conversely, bare land experienced a notable decrease of 56.98%, highlighting the conversion of natural areas into built-up environments. Urban green spaces exhibited a concerning decrease of 1.98%, emphasising the challenges faced in preserving green areas amidst rapid urban expansion. The decrease in road coverage by 87.45% suggests potential changes in infrastructure planning strategies. This substantial reduction implies that a significant portion of the roads identified in 2016 have been absorbed into the expanding built-up areas in Lusaka. This transformation reflects a prioritisation of land allocation towards urban expansion, at the expense of maintaining or extending road networks. The conversion of roads into built-up zones underscores the rapid urbanisation unfolding in the city, where land is increasingly devoted to residential and commercial purposes rather than transportation infrastructure. Unexpectedly, there was a notable increase of 152.72% in water bodies, prompting the need for a thorough investigation into potential environmental impacts and water resource management techniques. These statistics underscore the urgency of intervention to preserve Lusaka's environmental balance and prioritise the protection and enhancement of urban green spaces. While the study provided valuable insights, limitations such as potential inaccuracies in satellite imaging and the narrow temporal scope of seven years must be acknowledged. These constraints emphasise the importance of cautious interpretation and highlight the necessity for further research to refine methodologies and enhance accuracy in assessing urban green spaces. Immediate action is imperative to address the deterioration of Lusaka's urban green areas. Robust regulations must be implemented to safeguard existing green spaces while integrating sustainability into urban planning processes. Community engagement plays a pivotal role in raising awareness and fostering active participation in preservation efforts. Collaborative efforts involving residents, environmental organisations, and governmental bodies are essential for the effective protection and management of urban green spaces. In conclusion, the study underscores the critical role of remote sensing technology and GIS analysis in monitoring urban green spaces and identifying threats to environmental sustainability. It provides a crucial basis for action, emphasising the need for coordinated efforts among stakeholders to preserve Lusaka's green spaces and promote sustainable urban development. Continued research is essential to deepen our understanding of urbanisation dynamics and formulate comprehensive policies for long-term environmental preservation and urban planning.

Acknowledgements

Conflict of Interests
The authors declare no conflict of interest.

References
Agency, Z. S. (2022). Census of Population And Housing Preliminary Report. Zambia Statistics Agency. Retrieved April 12, 2024, from https://www.zamstats.gov.zm/wp-content/uploads/2023/05/2022-Census-of-Population-and-Housing-Preliminary.pdf

Afara, A., Amen, M. A., Ayoubi, M. El, Ramadhan, D., & Alani, J. (2024). Arguing Faux Biophilia Concepts in F&B Interior Design: A Case Study Applied in Duhok City. Civil Engineering and Architecture, 12(2), 1091–1103. https://doi.org/10.13189/cea.2024.120231

Amen, M. A., Afara, A., & Muhy-Al-din, S. S. (2024). The Persuasibility of Globe Thermometer in Predicting Indoor Thermal Comfort Using Non-standard Globe Diameter: Row Houses of Semi-Arid Climates as Case Studies. Civil Engineering and Architecture, 12(1), 425–435. https://doi.org/10.13189/cea.2024.120132

Blaschke, T. (2010). Object based image analysis for remote sensing. ISPRS journal of photogrammetry and remote sensing, 65(1), 2-16. https://doi.org/10.1016/j.isprsjprs.2009.06.004

Dijkstra, L., Hamilton, E., Lall, S., & Wahba, S. (2020). How do we define cities, towns, and rural areas. World Bank Blogs, 10.

Franklin, J. (2001). Geographic information science and ecological assessment. In A Guidebook for Integrated Ecological Assessments (pp. 151-161). New York, NY: Springer New York. http://dx.doi.org/10.1007/978-1-4419-8620-7_12

Gülçin, D., & Akpınar, A. (2018). Mapping Urban Green Spaces Based on an Object-Oriented Approach. Bilge International Journal of Science and Technology Research, 2, 71-81. https://doi.org/10.30516/bilgesci.486893

Esteban Rossi-Hansberg, Mark L. J. Wright, Urban Structure and Growth, The Review of Economic Studies, Volume 74, Issue 2, April 2007, Pages 597–624, https://doi.org/10.1111/j.1467-937X.2007.00432.x

JICA. (2009, March 4). The Study On Comprehensive Urban Development Plan For The City Of Lusaka In The Republic Of Zambia. The Study On Comprehensive Urban Development Plan For The City Of Lusaka In The Republic Of Zambia.

Retrieved May 9, 2024, from https://openjicareport.jica.go.jp/pdf/11932845_01.pdf

Kerselaers, E., Rogge, E., Vanempten, E., Lauwers, L., & Van Huylenbroeck, G. (2013). Changing land use in the countryside: Stakeholders' perception of the ongoing rural planning processes in Flanders. Land use policy, 32, 197-206. https://doi.org/10.1016/j.landusepol.2012.10.016

Kim, J., Kim, D. H., Lee, J., Cheon, Y., & Yoo, S. (2022). A scoping review of qualitative geographic information systems in studies addressing health issues. Social Science & Medicine, 314, 115472. https://doi.org/10.1016/j.socscimed.2022.115472

Koskivaara, Atte & Lähtinen, Katja (2023) Land-Use Planning in Municipalities as a Driver for Sustainable Residential Building in Finland: A Regional Innovation System Approach. Journal of Sustainability Research. https://doi.org/10.20900/jsr20230006

Li, Y., Zhao, Q., & Zhong, C. (2022). GIS and urban data science. Annals of GIS, 28(2), 89–92. https://doi.org/10.1080/19475683.2022.2070969

Loureiro, A., & Veloso, T. J. (2014). Outdoor exercise, well-being and connectedness to nature. Psycho, 45(3), 299-304. https://doi.org/10.13140/2.1.1219.1526

Luan, C., Liu, R., & Peng, S. (2021). Land-use suitability assessment for urban development using a GIS-based soft computing approach: A case study of Ili Valley, China. Ecological Indicators, 123, 107333. https://doi.org/10.1016/j.ecolind.2020.107333

Michalak, W. Z. (1993). GIS in land use change analysis: integration of remotely sensed data into GIS. Applied geography, 13(1), 28-44. https://doi.org/10.1016/0143-6228(93)90078-F

Nyimbili, P. H., Chalwe, N., Kawimbe, B. J., Lubilo, F., Mwanaumo, E. M. U., Thwala, W. D., & Erden, T. (2023, June). Quantifying the Effect of the Built Environment on Surface Runoff using GIS and Remote Sensing: A Case Study of Ibex Hill-Lusaka. In Proceedings of the International Conference of Contemporary Affairs in Architecture and Urbanism-ICCAUA (Vol. 6, No. 1, pp. 506-518). https://doi.org/10.38027/iccaua2023en0327

Ren, & Malik. (2003, October). Learning a classification model for segmentation. In Proceedings ninth IEEE International Conference on Computer Vision (pp. 10-17). IEEE.doi: 10.1109/ICCV.2003.1238308.

Sedogo, L. G. (2002). Integration of local participatory and regional planning for resources management using remote sensing and GIS.

Simwanda, M., & Murayama, Y. (2018). Spatiotemporal patterns of urban land use change in the rapidly growing city of Lusaka, Zambia: Implications for sustainable urban development. Sustainable cities and society, 39, 262-274. https://doi.org/10.1016/j.scs.2018.01.039

Tassi, A., Gigante, D., Modica, G., Di Martino, L., & Vizzari, M. (2021). Pixel-vs. Object-based landsat 8 data classification in google earth engine using random forest: The case study of maiella national park. Remote sensing, 13(12), 2299. https://doi.org/10.3390/rs13122299

Tassi, A., & Vizzari, M. (2020). Object-oriented lulc classification in google earth engine combining snic, glcm, and machine learning algorithms. Remote Sensing, 12(22), 3776. https://doi.org/10.3390/rs12223776

Yin, J., Dong, J., Hamm, N. A., Li, Z., Wang, J., Xing, H., & Fu, P. (2021). Integrating remote sensing and geospatial big data for urban land use mapping: A review. International Journal of Applied Earth Observation and Geoinformation, 103, 102514. https://doi.org/10.1016/j.jag.2021.102514